NACA

RESEARCH MEMORANDUM

EXPERIMENTAL INVESTIGATION OF A 7-INCH-TIP-DIAMETER TRANSONIC TURBINE

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Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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EXPERIMENTAL INVESTIGATION OF A 7-INCH-TIP-DIAMETER TRANSONIC TURBINE

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SUMMARY

The over-all performance results have been obtained for a 7-inch transonic turbine, and the results are compared with those of a 14-inch turbine of geometrically similar design that was previously investigated. The peak efficiency obtained with the turbine was 0.85, which was 2 points lower than that obtained previously with the 14-inch turbine. The difference noted in over-all performance as a result of decreasing the tip diameter from 14 to 7 inches was considered significantly small. The difference could not be interpreted theoretically as a Reynolds number effect. Therefore, the size effect on performance is believed to be due largely to the inability to fabricate the smaller blades to the same percentage of dimensional deviation as that of the larger blades.

INTRODUCTION

In recent years there has been an increasing interest in turbines for such applications as missile propellant-pump drive, missile auxiliary power drive, aircraft refrigeration, and aircraft auxiliary power drive. Because of the increased interest in this field, a considerable amount of the turbine research effort at the NACA Lewis laboratory has been directed toward this class of turbines, especially those for missile propellant-pump drive. Because many of these applications result in turbines that are small compared with current jet-engine turbines, the initial phase of the experimental program was a limited investigation to determine the effect of turbine size on over-all performance. The turbine used for the investigation was a 7-inch-tip-diameter transonic turbine with zero suction-surface diffusion. The turbine design method and the performance obtained with a 14-inch cold-air model of the turbine are discussed in references 1 and 2. The blading geometry, axial nozzle-rotor clearance and rotor-blade-tip clearance were scaled one-half the size of the turbine of reference 1. The 7-inch turbine was constructed, and its cold-air performance was determined. The turbine

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was investigated with an inlet temperature of 600° R and with inlet pressures of 32 and 64 inches of mercury absolute.

This report presents the experimental results obtained with the 7-inch transonic turbine. The performance results of the 14-inch turbine of reference 1 are included. A comparison of the performance of the two turbines is made, and the effect of turbine size on performance is discussed.

SYMBOLS

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The following symbols are used in this report:

$\Delta h'$	specific work output, Btu/lb
N	rotative speed, rpm
p	pressure, lb/sq ft
r	radius, ft
U	blade velocity, ft/sec
V	absolute gas velocity, ft/sec
W	relative gas velocity, ft/sec
w	weight flow, lb/sec
γ	ratio of specific heats
δ	ratio of inlet-air total pressure to NACA standard sea-level pressure p_0'/p^*
ε	function of γ, $\gamma^*/\gamma\left[\dfrac{\left(\dfrac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}}}{\left(\dfrac{\gamma^*+1}{2}\right)^{\frac{\gamma}{\gamma^*-1}}}\right]$
η_t	adiabatic efficiency based on total-pressure ratio
θ_{cr}	squared ratio of critical velocity at turbine inlet to critical velocity at NACA standard sea-level temperature, $(V_{cr,0}/V_{cr}^*)^2$

Subscripts:

cr	conditions at Mach number of unity
t	tip
x	axial direction
0	station upstream of stator
1,2,3,4,5	stations between 0 and 6 (fig. 2)
6	station downstream of rotor

Superscripts:

'	total state
*	NACA standard conditions

APPARATUS AND PROCEDURE

The stator and rotor blading used in this investigation were specified to be exactly one-half the size of those of reference 1. The 37 rotor blades were machined from aluminum alloy, and the 32 stator blades were made from steel alloy. The stator and rotor blade coordinates are given in tables I and II. The turbine rotor assembly was turned to a tip diameter of 6.970 inches which resulted in a radial tip clearance of 0.015 inch. A photograph of the rotor is shown in figure 1. The turbine velocity diagram is the same as that of reference 1 and is included herein for convenience (fig. 2). A diagrammatic sketch of the turbine test section is shown in figure 3. The turbine was operated with dry pressurized air from the laboratory combustion-air system. The air passed through a filter tank, a steam-heat exchanger and an electric heater, a hydraulically operated inlet-control valve, an ASME flat-plate orifice, and then to the turbine-inlet collector. After the air passed through the turbine, it was directed to the laboratory altitude-exhaust system. The turbine power output was absorbed with a cradled direct-current dynamometer.

The airflow through the turbine was measured by the ASME orifice, for which the discharge coefficient had been obtained experimentally. The turbine-inlet temperature was measured with three bare-wire thermocouples located at the area center radii of three equal annular areas. The turbine-inlet and -outlet pressures were measured with mercury manometers. The static pressure was measured with four static taps located 90° apart on the inner and outer walls at both axial locations. The rotor-outlet, absolute-flow angle was measured with an angle-sensitive probe mounted in a self-alining probe actuator. Angle readings were obtained at four radial positions corresponding to the area center radii of four equal annular areas. The turbine-output torque was measured with a commercial self-balancing torque cell and an acetylene tetrabromide manometer. Turbine rotative speed was measured with an electronic events-per-unit-time meter.

The actual specific work output was computed from the torque, speed, and weight flow. In computing the specific work output, no correction was made to include the friction loss of the turbine bearings. The subject turbine was equipped with low-friction-type bearings, and the bearing loss was deemed sufficiently small to be well within experimental error. The turbine-outlet total temperature was obtained from the inlet total temperature and the specific work output. The total pressure at the turbine inlet and outlet was computed from the static pressure, weight flow, flow angle, and total temperature per equations 7 and 9 of reference 3.

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Performance runs were made at speeds from 60 to 120 percent of design speed. At each speed the pressure ratio was varied from about 1.5 to the turbine limiting-loading pressure ratio. Turbine-inlet pressure was maintained constant at 32 inches of mercury absolute for one set of data and 64 inches for the other set. Turbine-inlet temperature was maintained at 600° R.

RESULTS AND DISCUSSION

The over-all performance of the 7-inch transonic turbine is shown in figure 4. Figure 4(a) shows the turbine performance for inlet conditions of 32 inches of mercury and 600° R. The equivalent specific work output $\Delta h'/\theta_{cr}$ is shown as a function of the weight-flow - speed parameter $\varepsilon wN/\delta$ for the various pressure ratios, with the constant speed lines and efficiency contours superimposed. The maximum efficiency obtained for the turbine was 0.85, which occurred at design speed and over a total-pressure-ratio range including 2.0 and 2.1. As can be seen from figure 4(a), design specific work output was not achieved before limiting-load occurred. The turbine could be made to extract design specific work by either (a) reducing the weight flow by reducing the stator throat area, or (b) enlarging the rotor passage area. Experience with the larger turbines has shown that small modifications of this kind, involving only a minute change in blading geometry, do not affect peak efficiency but do affect the pressure ratio and work output at which limiting-loading occurs. Thus, with modification, this turbine could be made to produce design work at, or near, peak efficiency.

The performance obtained with the 14-inch turbine of reference 1 is shown in figure 5. From a comparison of figures 4 and 5 it can be theorized that the difference in performance (2 efficiency points) is due to: (a) manufacturing tolerances or (b) Reynolds number effect, in addition to any experimental error. Manufacturing tolerence in blade fabrication, in the case of this blading and that of reference 1, was specified to give a maximum dimensional deviation of ±0.005 inch from design blade contour; this deviation is a function of the fabrication process rather than the blade size. Thus, the dimensional tolerance as
4711 a percentage of blade chord cannot be maintained between two blade sets that are of different sizes.

The Reynolds number for the 14-inch turbine (ref. 1) could be duplicated with the 7-inch turbine by operating it with an inlet pressure of 64 inches of mercury absolute. The performance obtained at this inlet pressure is shown in figure 4(b). From a comparison of figure 4(b) with figure 4(a), the effect of Reynolds number on over-all performance appears to be very small for the range of Reynolds number encountered. The over-all performance obtained at the two different inlet pressures is substantially the same. Also, for the turbine of reference 4, no definite trend of turbine performance as effected by inlet pressure over the range of conditions investigated was found. These results should not be construed to indicate that over-all performance is generally not effected by Reynolds number, and it can be shown theoretically from a simple consideration of turbulent-boundary-layer theory that aerodynamic viscous losses would be expected to decrease as Reynolds number is increased. However, experimental results have shown in many cases that for a change of Reynolds number of this magnitude, over the Reynolds number range encountered, the effect on over-all performance is either very small or not discernible. Thus, from a consideration of the factors involved, the difference in performance between that of the 7-inch turbine and that of the 14-inch turbine is believed to be due largely to manufacturing tolerences. Also felt to be significant are the facts that good performance can be obtained with the 7-inch turbine, which operates with transonic relative velocity through the rotor, and that the size effect on performance is quite small.

CONCLUDING REMARKS

A transonic turbine with a 7-inch tip diameter has been investigated experimentally, and the performance results are compared with those obtained previously with a 14-inch turbine of geometrically similar design. A peak efficiency of 0.85 was obtained with the turbine; this represents a decrease of 2 points from that obtained with the 14-inch turbine. The reduction in peak efficiency that was effected by decreasing the turbine size from 14 to 7 inches was felt to be significantly small. The difference in efficiency, noted herein, effected by the turbine size could not be interpreted purely as a Reynolds number effect. Thus, this difference is believed to result largely from the inability to fabricate the smaller blading to the same percent of dimensional deviation as obtained for the larger turbine blades.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, October 30, 1957

REFERENCES

1. Whitney, Warren J., Monroe, Daniel E., and Wong, Robert Y.: Investigation of Transonic Turbine Designed for Zero Diffusion of Suction-Surface Velocity. NACA RM E54F23, 1954.

2. Stewart, Warner L., Wong, Robert Y., and Evans, David G.: Design and Experimental Investigation of Transonic Turbine with Slight Negative Reaction Across Rotor Hub. NACA RM E53L29a, 1954.

3. Rohlik, Harold E., Wintucky, William T., and Scibbe, Herbert W.: Investigation of a 0.6 Hub-Tip Radius-Ratio Transonic Turbine Designed for Secondary-Flow Study. I - Design and Experimental Performance of Standard Turbine. NACA RM E56J16, 1957.

4. Schum, Harold J.: Performance Evaluation of Reduced-Chord Rotor Blading as Applied to J73 Two-Stage Turbine. V - Effect of Inlet Pressure on Over-All Performance at Design Speed and Inlet Temperature of 700° R. NACA RM E53L16b, 1957.

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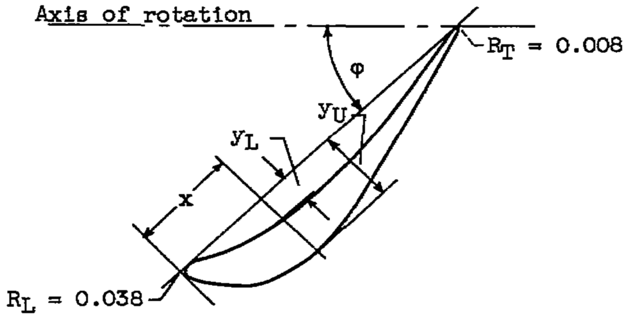
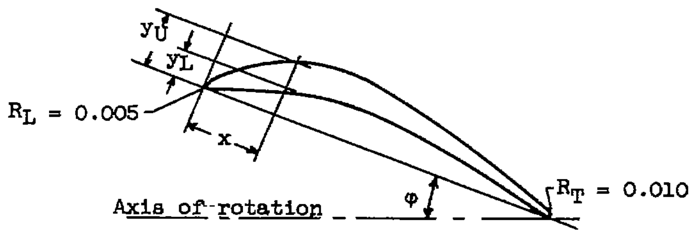
TABLE I. - STATOR-BLADE-SECTION COORDINATES



x, in.	Hub		Mean		Tip	
	φ, deg					
	50.1		44.9		40.5	
	r/r_t					
	0.70		0.85		1.00	
	y_L, in.	y_U, in.	y_L, in.	y_U, in.	y_L, in.	y_U, in.
0	0.038	0.038	0.038	0.038	0.038	0.038
.05	.002	.113	.002	.112	.002	.114
.10	.038	.147	.030	.150	.030	.156
.15	.066	.168	.055	.174	.054	.185
.20	.084	.179	.074	.189	.072	.206
.25	.097	.188	.090	.196	.088	.218
.30	.104	.182	.100	.198	.100	.225
.35	.108	.176	.108	.196	.110	.226
.40	.108	.166	.112	.189	.116	.222
.45	.106	.152	.112	.179	.120	.216
.50	.100	.138	.111	.166	.121	.204
.55	.092	.123	.107	.153	.120	.192
.575	.088	.115	.105	.149	.119	.185
.60	.083	.108	.101		.118	.182
.65	.071		.093		.113	.168
.70	.060		.084		.110	
.75	.044		.072		.100	
.80	.030	Straight line	.060		.091	
.85	.016		.048	Straight line	.080	
.90	.001		.035		.070	
.906	.0005	.014	----		----	
.912	.008	.008	----		----	Straight line
.925	----	----	.028		.064	
1.00	----	----	.008		.044	
1.025	----	----	.002	.016	.038	
1.034	----	----	.008	.008	----	
1.125	----	----	----	----	.009	.024
1.164	----	----	----	----	.008	.008

TABLE II. - ROTOR-BLADE-SECTION COORDINATES



x, in.	Hub		Mean		Tip	
	φ, deg					
	-3.3		7.9		19.9	
	r/r_t					
	0.70		0.85		1.00	
	y_L, in.	y_U, in.	y_L, in.	y_U, in.	y_L, in.	y_U, in.
0.00	0.005	0.005	0.005	0.005	0.005	0.005
.05	.044	.071	.040	.069	.030	.058
.10	.091	.128	.084	.128	.062	.106
.15	.132	.182	.120	.178	.088	.148
.20	.168	.232	.152	.224	.112	.186
.25	.200	.278	.180	.267	.132	.218
.30	.228	.318	.202	.303	.150	.244
.35	.252	.355	.221	.333	.165	.266
.40	.273	.385	.237	.358	.178	.283
.45	.290	.410	.249	.376	.190	.296
.50	.304	.428	.259	.388	.198	.306
.55	.316	.442	.266	.396	.206	.312
.60	.326	.450	.272	.399	.212	.315
.65	.333	.454	.274	.398	.215	.316
.70	.338	.452	.274	.392	.216	.313
.75	.338	.446	.271	.382	.215	.306
.80	.334	.435	.266	.369	.212	.298
.85	.326	.420	.258	.352	.206	.286
.90	.315	.400	.248	.332	.198	.270
.95	.300	.376	.234	.308	.188	.254
1.00	.280	.348	.219	.282	.176	.235
1.05	.256	.316	.202	.255	.164	.216
1.10	.230	.280	.181	.226	.149	.194
1.15	.199	.243	.158	.196	.134	.173
1.20	.165	.203	.133	.164	.117	.152
1.25	.129	.168	.106	.134	.100	.130
1.30	.091	.121	.078	.102	.082	.108
1.35	.052	.080	.048	.072	.063	.087
1.40	.012	.038	.018	.040	.044	.066
1.429	.010	.010	----	----	----	----
1.443	----	----	.010	.010	----	----
1.45	----	----	----	----	.023	.044
1.50	----	----	----	----	.002	.022
1.516	----	----	----	----	.010	.010

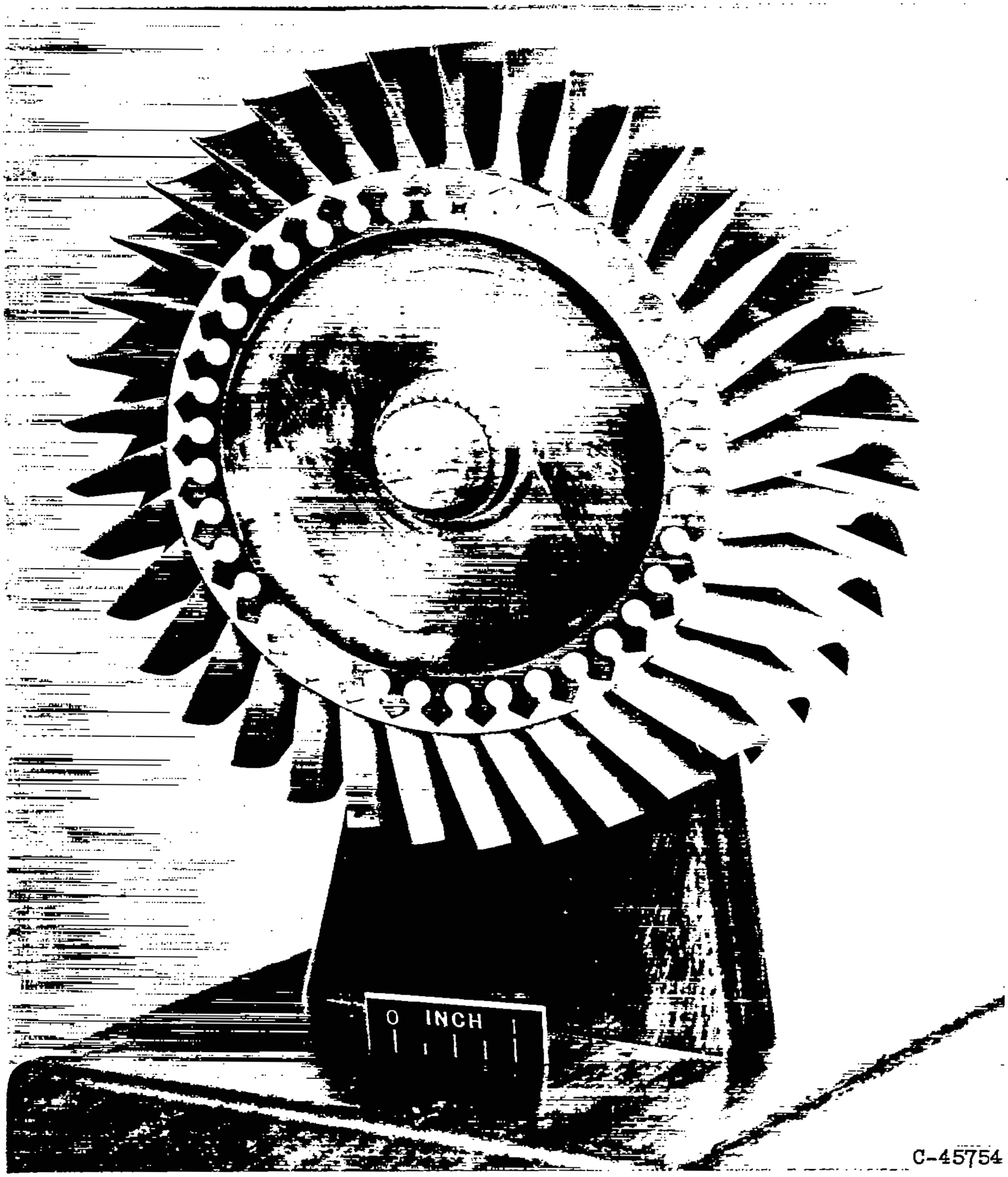
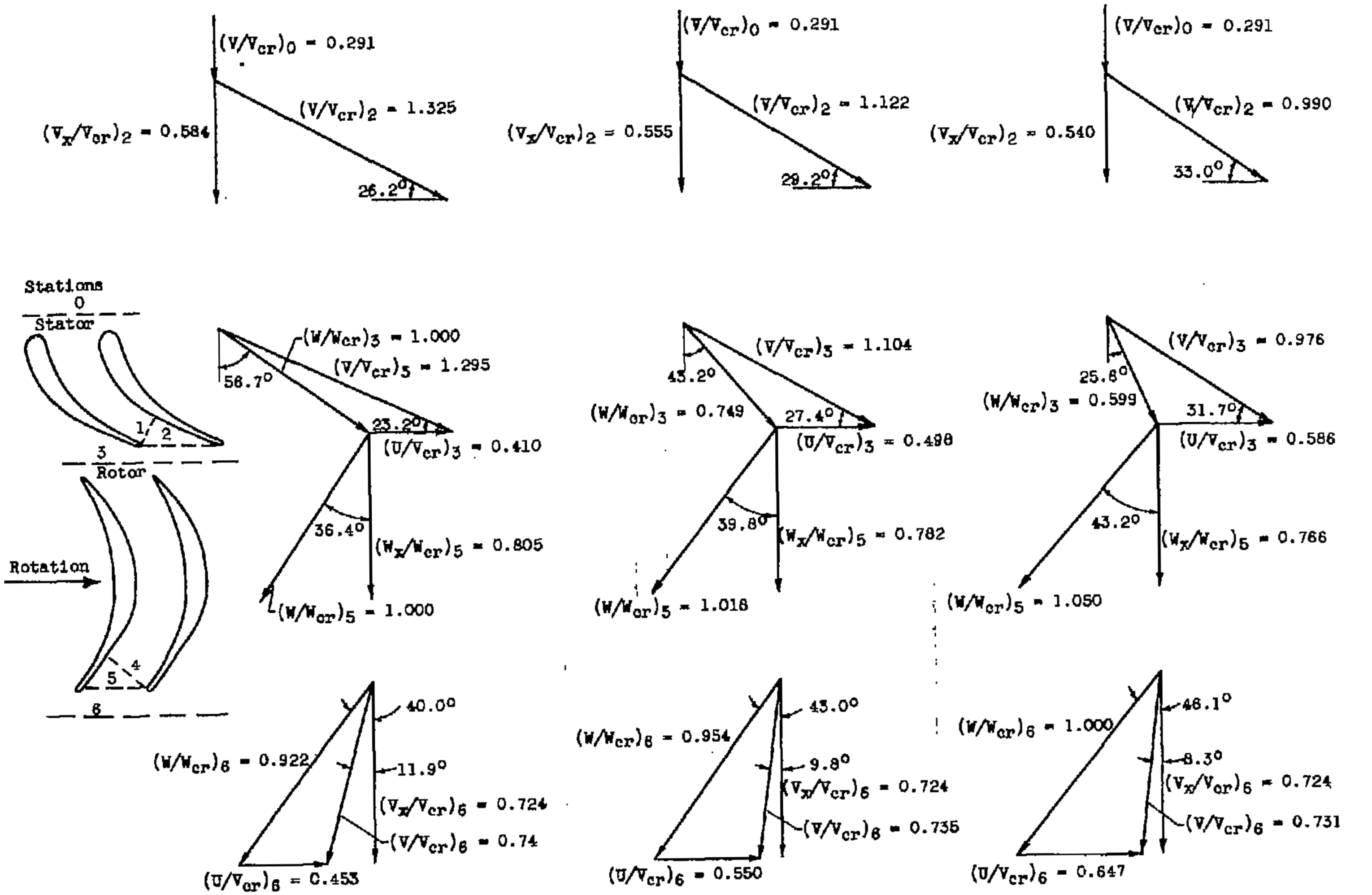


Figure 1. - Photograph of 7-inch transonic turbine rotor.



(a) Hub; r/r_t, 0.70.

(b) Mean; r/r_t, 0.85.

(c) Tip; r/r_t, 1.00.

Figure 2. - Transonic-turbine velocity diagrams.

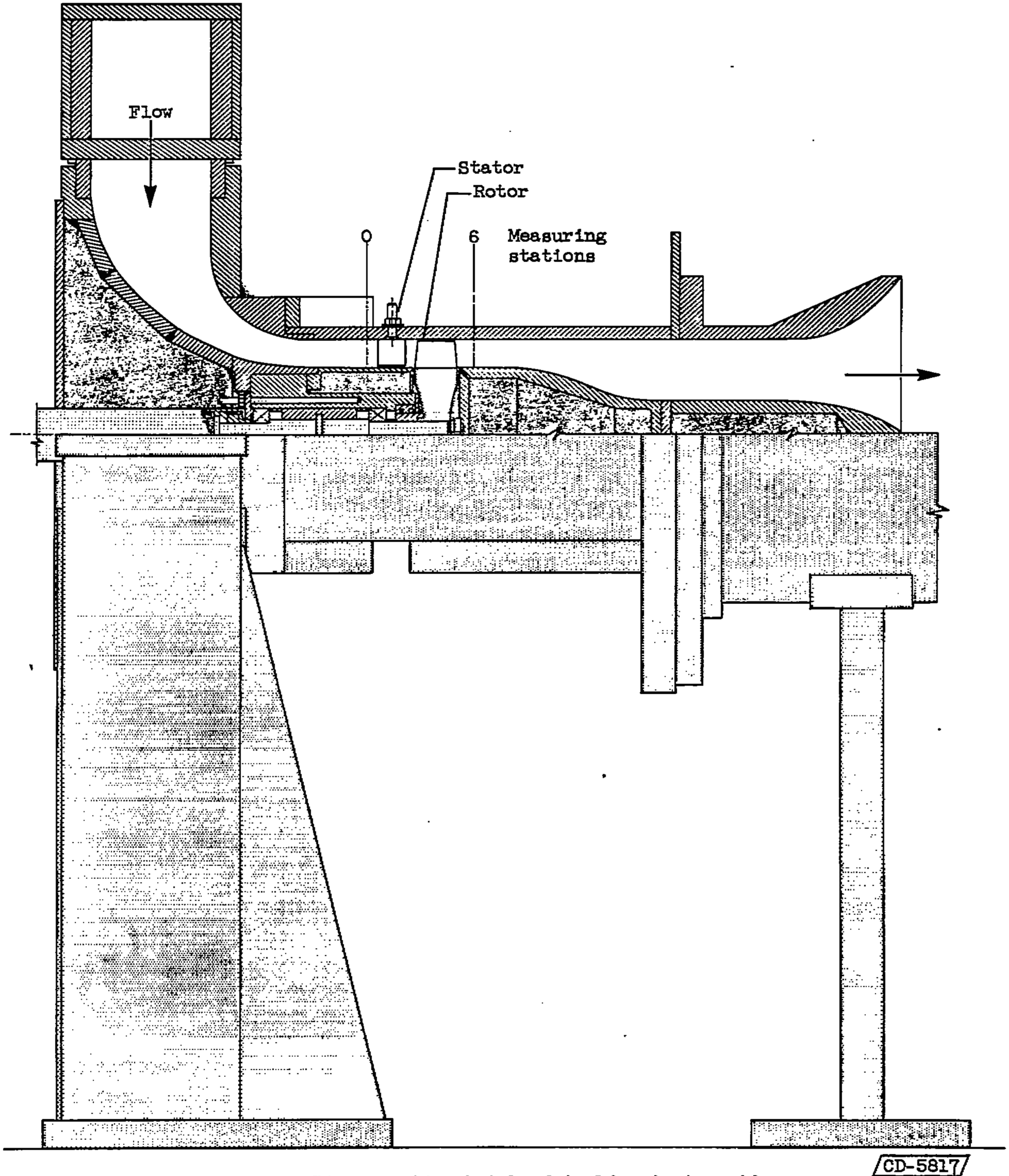
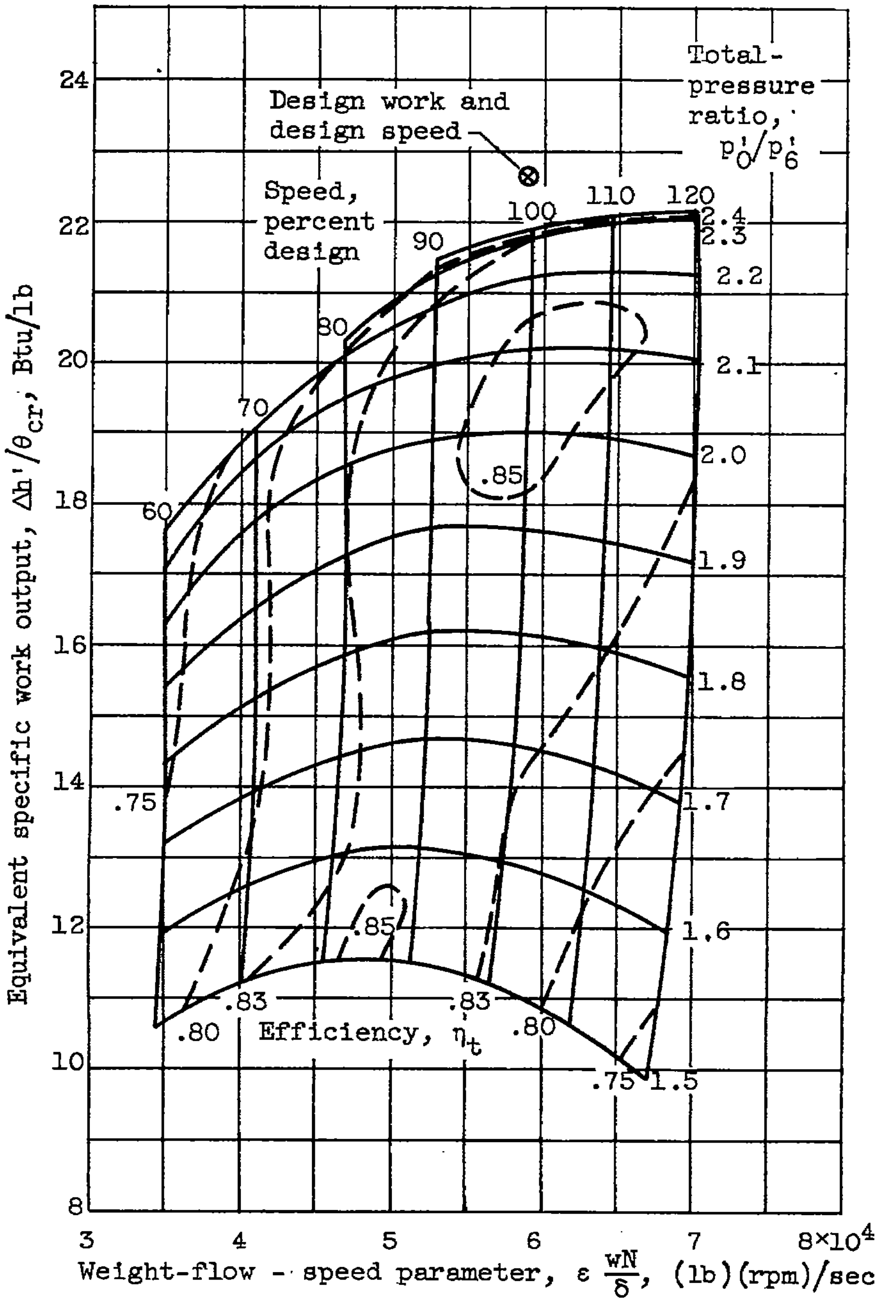
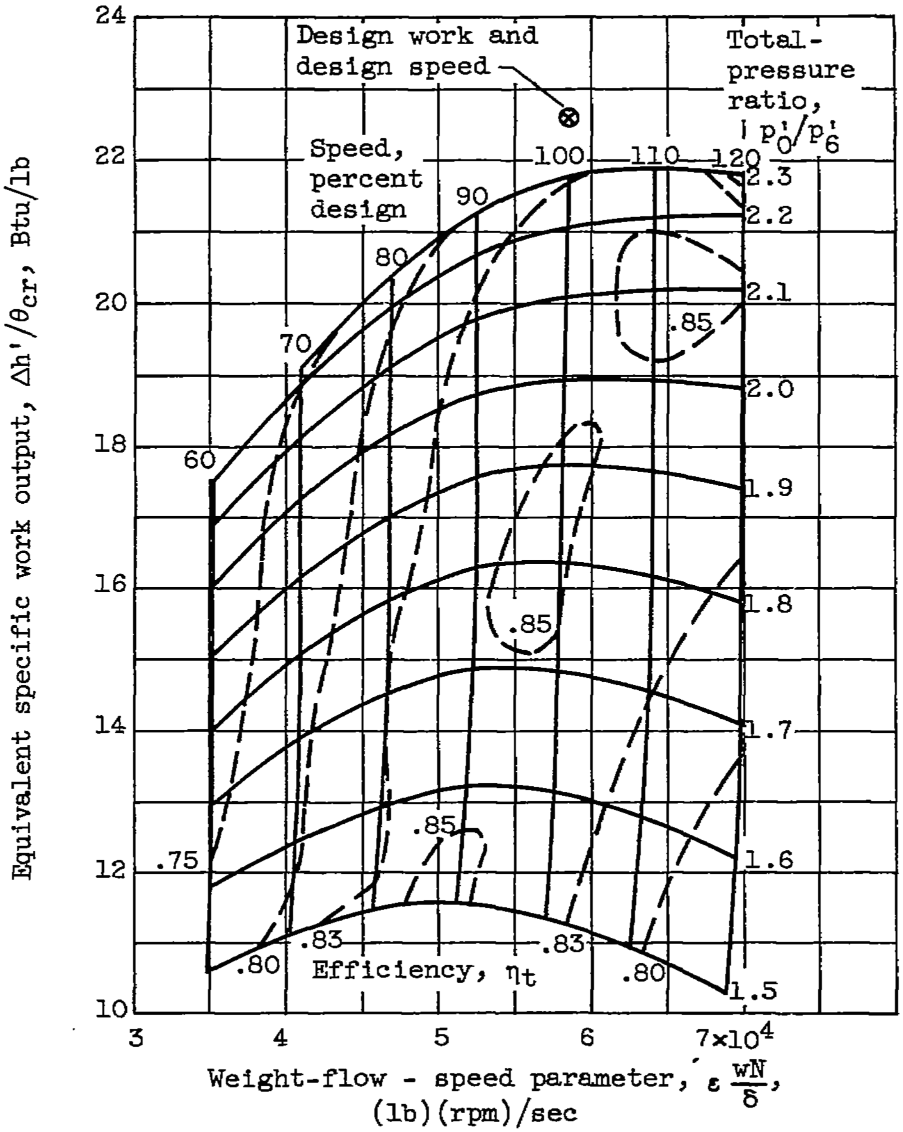


Figure 3. - Diagrammatic sketch of turbine test section.



(a) Inlet pressure, 32 inches of mercury absolute.

Figure 4. - Over-all performance of 7-inch turbine; inlet temperature, 600° R.



(b) Inlet pressure, 64 inches of mercury absolute.

Figure 4. - Concluded. Over-all performance of 7-inch turbine; inlet temperature, 600° R.

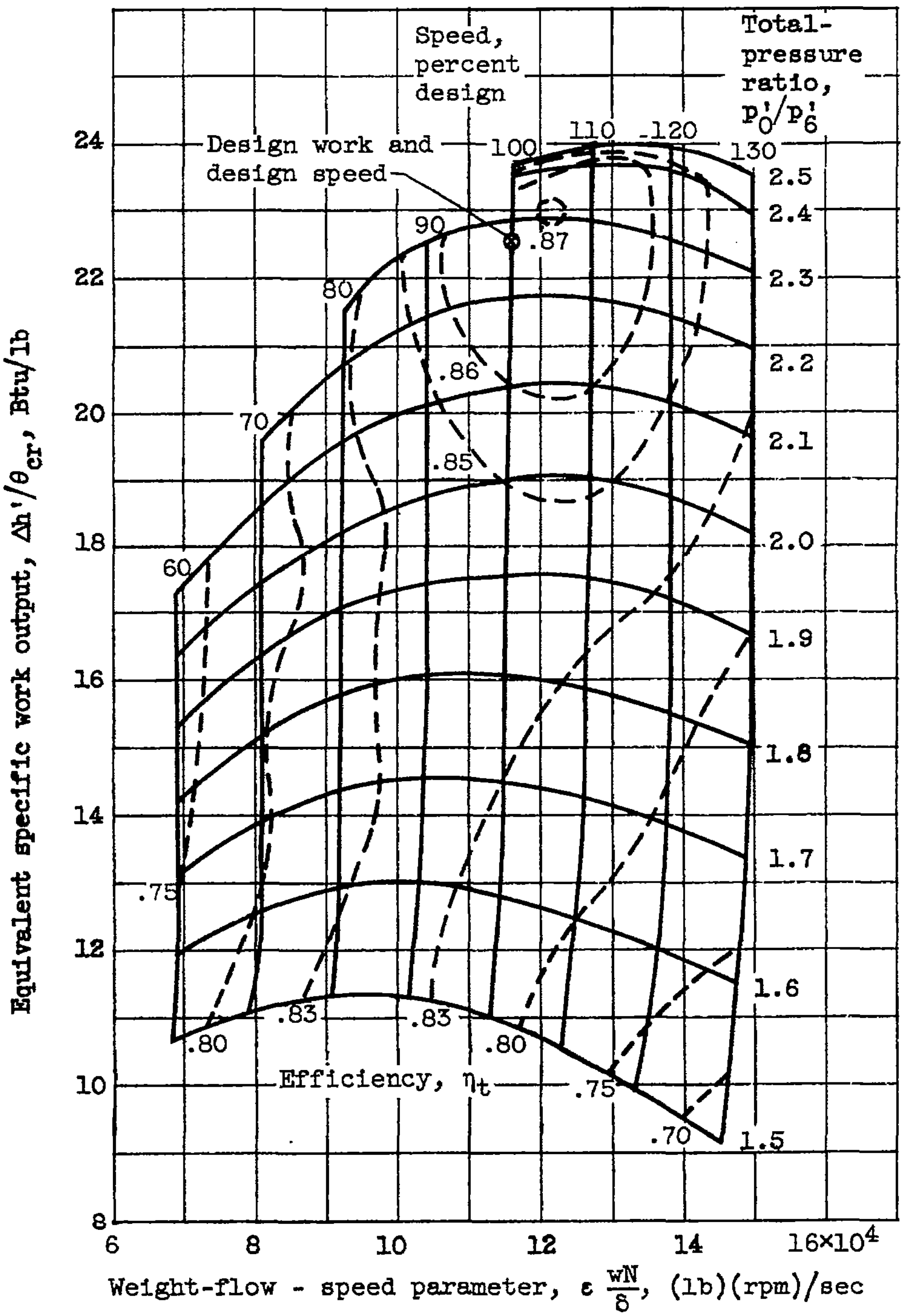


Figure 5. - Over-all performance of 14-inch turbine.

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